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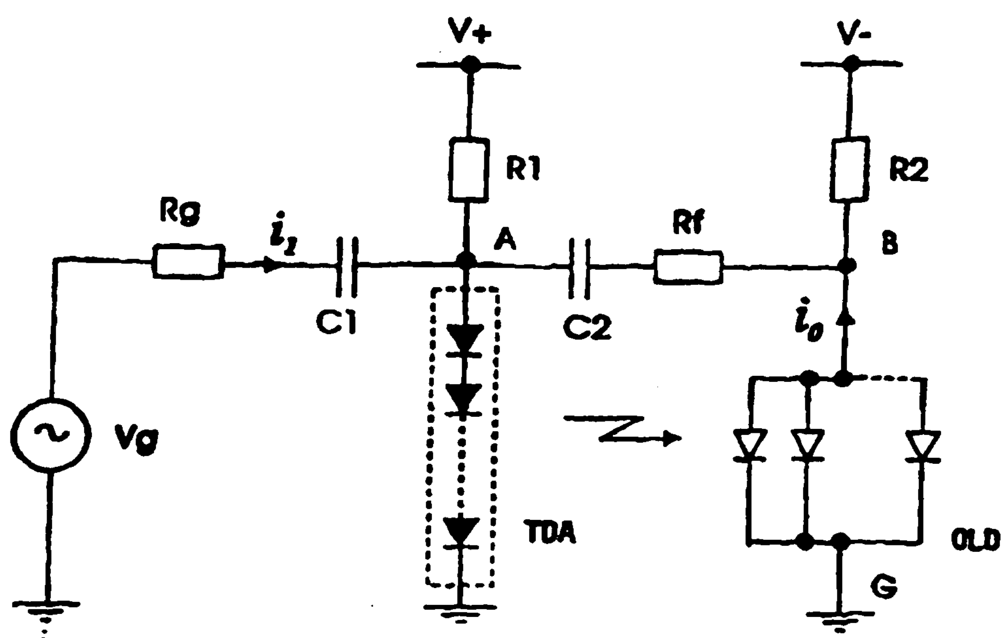
(54) Title: A LOW NOISE PHOTON COUPLED CIRCUIT

(57) Abstract

A photon coupled circuit comprises a high quantum efficiency semiconductor light emitter (TDA) coupled with high quantum efficiency with a semiconductor light detector (OLD). Bias current is provided to both the light detector (OLD) and light emitter (TDA). The light output of the light emitter (TDA) is modulated by the current flowing therein and the current flowing (i_o) in the detector (OLD) is modulated by the light received from the light emitter (TDA). The quantum transfer efficiency or current gain in greater that 0.5 and a portion of the current flowing in the light detector (OLD) is applied as feedback to reinforce or oppose the curent flowing in the light emitter (TDA).



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TITLE: "A LOW NOISE PHOTON COUPLED CIRCUIT"

Technical Field

This invention relates to optoelectronic coupling and more particularly to a photon coupled circuit for applications including low noise optocoupling, optical interconnects, current amplifiers, light amplifiers and optical bistable devices. As used herein, the term "photon coupled circuit" refers to a configuration of optoelectronic devices which are photonically and electronically coupled.

Background Art

Many prior art devices achieve a current amplification by the use of active electronic circuits. Such devices are not able to offer a low noise operation and in particular are often limited by the shot noise in the system. Australian patent 648682 describes an optoelectronic device in which the noise is suppressed below the normal shot noise.

Disclosure of Invention

It is an object of this invention to provide a sub-shot noise photon coupled circuit which incorporates feedback to provide high gain or wide bandwidth characteristics.

Accordingly, in one aspect this invention consists in a low noise photon coupled circuit comprising a high quantum efficiency semiconductor light emitter; means to provide a bias current to said light emitter, the light output of said light emitter being modulated by the current flowing therein; a semiconductor light detector optically coupled with high quantum efficiency with said light emitter, means to provide a bias current to said light detector, the current flowing in said light detector being modulated by the light received from said light emitter, the quantum transfer efficiency of said circuit being greater than 0.5, and means to apply a feedback portion of the current flowing in said light detector to reinforce or oppose the current flowing in the light emitter.

In one form of the invention the feedback is positive to reinforce the current flowing in the light emitter and provide current gain exceeding unity. In another form of the invention the feedback is negative to oppose current flowing in the light emitter and provide an increased

bandwidth. As used herein, the term quantum transfer efficiency refers to the efficiency of the transfer of the current modulating the light emitter into current flowing in the light detector. It is therefore equal to the current gain of the circuit.

In one form of the invention the light emitter comprises an array of high quantum efficiency laser diodes or light emitting diodes which are modulated by a common current modulator.

In one form of the invention, the product of the number of elements in the array and the value of the quantum coupling efficiency between each element and the light detector is much greater than 1. In this case the quantum partition noise introduced in the coupling between the light emitting array and the detecting system is negligible.

In another form of the invention, employing a single light emitter the quantum transfer efficiency preferably exceeds 0.75 and ideally is as close to unity as possible.

Preferably, the light detector comprises a PIN photo diode.

The high quantum efficiency coupling between the light emitter and the light detector is preferably achieved by close physical positioning as for example, in an optoelectronic integrated circuit (OEIC) through and selection of high quantum efficiency devices. High efficiency coupling can also involve the use of an optical waveguide or a high efficiency light pipe.

In one form of the invention the current in the light emitter is preferably modulated by the current output of an additional light detector. The device then functions as a light receiver. In an alternative arrangement an input light signal from an external source is received by the light detector and the current flowing in the light detector is modulated by the input light signal.

In another form of the invention the current flowing in the light detector is used to drive individual or arrays of laser diodes or light emitting diodes.

The photon coupled circuit of this invention can be used as the basis of an optocoupler, amplifier, optoelectronic oscillator, optoelectronic multivibrator or optoelectronic bistable device.

Brief Description of Drawings

One embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 shows a photon coupled current amplifier according to this invention;

Fig. 2 shows an AC equivalent circuit of the amplifier shown in Fig. 1;

Fig. 3 shows (a) current gain, (b) voltage gain and (c) power gain of the photon coupled amplifier shown in Fig. 1;

Fig. 4 is an AC equivalent circuit of the photon coupled amplifier used for noise calculations;

Fig. 5 is a plot of current gain of the photon coupled amplifier with feedback resistance equal to (a) 30, (b) 15 and (c) 7.5 k ohms.

Fig. 6 is a plot of the frequency spectra of the photon coupled amplifier output currents of (a) signal and (b) noise;

Fig. 7 shows a plot of a noise figure variation with a source resistance at different quantum efficiencies;

Fig. 8 shows a second embodiment of a photon coupled amplifier according to this invention; and

Fig. 9 shows a third embodiment of a photon coupled amplifier according to this invention.

Best Modes for Carrying Out the Invention

Fig. 1 shows the circuit of an optocoupler amplifier. An array of series connected semiconductor junction light emitting diodes (or laser diodes) TDA each of high quantum efficiency is shown modulated by a voltage source v_g with internal impedance R_g . It is connected to the array through a blocking capacitor C_1 and the DC bias current for the array is provided through resistance R_1 . The light from this array is efficiently collected by an array of PIN diodes OLD which is biased through resistance R_2 .

A fraction of the current output from the detector is fed back from point B through the feedback resistance R_f and the blocking capacitor C_2 to the input of the light emitting array at point A to provide positive current feedback. The amplified current output is available between points A and B or between B and G. The noise behaviour of the positive feedback amplifier will depend on the quantum efficiency of the optoelectronic conversion and the noise figure is expected to improve as the quantum efficiency is increased. In the following analysis, a LED model which has been found useful for both small signal and noise performance evaluations is used.

Let	N	=	number of LEDs in series
	η	=	differential quantum efficiency per device
	r_d	=	differential resistance of the LED
	r_s	=	bulk resistance of the LED
	r_{sd}	=	$r_s + r_d$
	R_1	=	bias resistance for the LED array
	R_2	=	includes the bias and load resistance at the output
	R_f	=	feedback resistance (or impedance in general).

The low-frequency small signal equivalent circuit for the system is shown in Fig. 2. It is assumed that the LEDs are identical and that the detector generates an output current given by $i_0 = N(\eta i_2)$, where i_2 is the signal current flowing through the LED array. The impedance of the detector is assumed to be high compared with R_f or R_2. With i_1 equal to the current from the signal source, it can readily be shown that the closed-loop current gain of the amplifier is given by

$$A_i = \frac{i_0}{i_1} = \frac{A_0}{1 - A_0\beta} \qquad (1)$$

where A_0 is the open-loop current gain given by

$$A_0 = N\eta\left(\frac{R_1}{R_1 + N r_{sd}}\right) \tag{2}$$

and β is the feedback factor given by

$$\beta = \frac{R_2}{R_f + R_2}\left(1 - \frac{r_{sd}}{\eta R_2}\right) \tag{3}$$

For stability reasons, the amplifier must operate such that the loop gain $A_0\,\beta$ is less than unity. If R_1 and R_2 are large compared with the device resistance r_{sd}, the open-loop gain becomes $N\eta$ and the feedback factor simplifies to $R_2/(R_f + R_2)$.

The input impedance of the opto-amplifier is given by

$$R_{inp} = \frac{v_1}{i_1} = \frac{A_i r_{sd}}{\eta} \tag{4}$$

The effect of the LED bias resistance R_1 on the input resistance is already included in the expression for the current gain.

It can also be shown that the voltage gain of the feedback amplifier is given by

$$A_v = \frac{v_0}{v_1} = 1 + \frac{R_f R_2}{R_f + R_2}\left(\frac{\eta}{r_{sd}} - \frac{1}{R_2}\right) \tag{5}$$

It will be noted that while the current gain is proportional to the number of LEDs in the array, the voltage gain is independent of N. When $R_f = \infty$, A_v reduces the open-loop value of

$\eta R_2/r_{sd}$. For a given circuit, the voltage gain increases as the LED bias current increases. This is because the device resistance decreases as the bias current goes up. The apparent power gain of the feedback amplifier is given by $P_0/P_1 = A_v A_i$, where $P_1 = v_1 i_1$ is the input signal power and $P_0 = v_0 i_0$ is the output signal power from the detector. Fig. 3 shows typical variations of current gain, voltage gain and power gain of the amplifier as a function of the feedback resistance.

At high frequencies, the LED junction can be represented by a parallel RC circuit. The rate of photons produced, n_p , is related to the diode injection current i_2 by

$$n_p = \frac{i_2/q}{1+j\omega\tau_c} \tag{6}$$

where τ_c is the charge recombination constant and q is the electronic charge. The detector current is given by

$$i_0 = N\eta n_p q = N\eta(\omega) i_2 \tag{7}$$

where $\eta(\omega) = \eta/(1+j\omega\tau_c)$. The high-frequency gain of the amplifier can be found using (2), (3) and (5) with η replaced by $\eta(\omega)$. Assuming the LED resistance to be small then $\beta = R_2/(R_f + R_2)$ and consequently

$$A_i = \frac{N\eta(\omega)}{1-N\eta(\omega)\beta} = \frac{N\eta}{1-N\eta\beta+j\omega\tau_c} \tag{8}$$

The 3 dB bandwidth is thus given by $(1-N\eta\beta)/\tau_c$ and the gain-bandwidth product is $N\eta/\tau_c$. This result is consistent with positive feedback, ie, an increase in low-frequency gain is accompanied by a corresponding reduction in bandwidth. While the GB product is independent of feedback, it is proportional to N which can be increased by using more LEDs in the array.

If wide bandwidth is of primary concern, negative feedback can be used. To implement negative feedback in the photon coupled amplifier of Fig. 1, the polarities of the detectors are reversed and the negative bias supply (V−) is replaced by a positive bias supply. This causes the detector current (i_0) to reverse in direction. The analysis of the negative feedback amplifier follows the same lines as for positive feedback except that i_0 is now given by $-N\eta i_2$, indicating a change of direction of current flow. In comparison with the positive feedback structure, $-\eta$ is assigned instead of η to equations (1)–(3) to give the current gain of the negative feedback opto-amplifier, ie.

$$A_I'=\frac{i_0}{i_1}=\frac{A_0'}{1-A_0'\beta'} \tag{9}$$

where A_0' is the open-loop current gain given by

$$A_0'=-N\eta\left(\frac{R_1}{R_1+Nr_{sd}}\right) \tag{10}$$

and β' is the feedback factor given by

$$\beta'=\frac{R_2}{R_f+R_2}\left(1+\frac{r_{sd}}{\eta R_2}\right) \tag{11}$$

For large values of R_1 and R_2 , the open-loop gain reduces to $A_0' = N\eta$ while the feedback factor becomes $\beta' = R_2/(R_f + R_2)$, which is equal to β in the case of positive feedback. Therefore the current gain is

$$A_i'=\frac{-N\eta}{1+N\eta\beta+j\omega\tau_c} \tag{12}$$

It can readily be shown that the magnitude of the amplifier gain will drop to $N\eta/(1+N\eta\beta)$ while the bandwidth increases to $(1+N\eta\beta)/\tau_c$, with GB again given by $N\eta/\tau_c$. By stacking a

number of high quantum efficiency LEDs in a negative feedback array amplifier, the bandwidth of the amplifier can be made to substantially exceed the intrinsic bandwidth ($1/\tau_c$) of a single LED.

The noise spectral density of the detector current consists of two components: the transmitted diode array current noise and the photon partition noise. The partition noise arises from the Bernoulli photon deletion process due to nonideal quantum efficiency. The photon current noise, on the other hand, is the sum of all the random events which independently modulate the injection current of the LED. It consists of the thermal noise of the circuit resistances, the short noise in the LEDs and the feedback of any current fluctuations in the detector, including partition noise. A low-frequency noise equivalent circuit of the positive feedback opto-amplifier is shown in Fig. 4. R_m represents the parallel combination of R_g and R_l, and the equivalent input voltage is given by $V_m = V_g (R_m / R_g)$. The RMS shot noise voltage of each LED is represented by $v_{sn} = i_s r_d$ where i_s is the RMS shot noise current. The thermal noise voltage associated with each of the resistances R_m, R_f, R_2 and Nr_s has been omitted from the figure for the sake of clarity.

It has been shown that the partition noise is given by

$$\langle i_p^2 \rangle = N\eta(1-\eta)2qI = N\eta(1-\eta)\langle i_s^2 \rangle \tag{13}$$

where q is the electronic charge, I the LED bias current, and $\langle i_s^2 \rangle$ $(=2qI)$ is the mean square shot noise current spectral density. Standard noise analysis of the circuit of Fig. 4 gives the transmitted photon current noise due to thermal and shot noise sources:

$$\langle i_a^2 \rangle = \left(\frac{N\eta}{1-N\eta\alpha}\right)^2 \left(\frac{2W}{\mu}\right)\langle i_s^2 \rangle \tag{14}$$

where

$$\alpha = \frac{\eta R_2 - r_{sd}}{\eta(R_f+R_2)} - \frac{r_{sd}}{\eta R_m} \tag{15}$$

$$W=\frac{r_d}{R_m}+\frac{r_d}{R_f+R_2}+N(\frac{r_d}{R_p})^2(\frac{r_s}{r_d}+\frac{\mu}{2}) \tag{16}$$

The total output noise current is given by

$$<i_{no}^2>=<i_a^2>+U^2<i_p^2> \tag{17}$$

where

$$U=1+\frac{N\eta}{1-N\eta\alpha}\,(\frac{R_2}{R_f+R_2}) \tag{18}$$

The second term in (17) represents the total effect of the partition noise, ie, it consists of the open-loop partition noise and the returned partition noise through the feedback loop.

Similar circuit analysis yields the output signal current

$$i_{so}=\frac{V_g}{R_g}\,\frac{N\eta}{1-N\eta\alpha} \tag{19}$$

where V_g is the input signal voltage. The output signal-to-noise ratio is therefore given by

$$SNR_o=\frac{(V_g/R_g)^2}{<i_s^2>}[\frac{2W}{\mu}+\frac{1-\eta}{N\eta}(1-N\eta\alpha)^2\ U^2]^{-1} \tag{20}$$

The input signal and noise are defined as the LED modulation currents due to the signal source V_g and the thermal noise of the source resistance R_g, respectively. Thus the input SNR is given by

$$SNR_i = V_g^2/4kTR_g = \frac{(V_g/R_g)^2}{<i_s^2>}(\frac{\mu Rg}{2r_d}) \tag{21}$$

where $r_d = \mu kT/qI$, μ being the ideality factor.

Finally, the noise figure of the feedback amplifier is given by

$$F = SNR_i/SNR_o = (\frac{\mu R_g}{2r_d})[\frac{2W}{\mu} + \frac{1-\eta}{N\eta}(1-N\eta\alpha)^2\ U^2] \tag{22}$$

To compare the noise figure of the feedback amplifier with the open-loop case R_l and R_2 are assumed for simplicity to be large compared with Nr_{sd} which leads to $\alpha = R_2/(R_f + R_2)$, $U = 1/(1-N\eta\alpha)$ and

$$W = \frac{r_d}{R_g} + N(\frac{r_d}{R_g})^2(\frac{r_s}{r_d} + \frac{\mu}{2}) \tag{23}$$

For the open-loop amplifier, $R_f \gg R_2$ so that α and 0 and $U = 1$. When feedback is used, $R_f \ll R_2$ so that $\alpha = 1$ and $U = 1/(1-N\eta)$. In both cases (22) simplifies to

$$F = 1 + \frac{Nr_d}{R_g}(\frac{r_s}{r_d} + \frac{\mu}{2}) + (\frac{1-\eta}{\eta})(\frac{\mu R_g}{2Nr_d}) \tag{24}$$

That is, under ideal bias conditions, the noise figure of the amplifier is independent of positive feedback. This is equivalent to saying that the output SNR of the amplifier is not affected by the applied feedback (as the input SNR may be fixed at a constant).

When $\eta=1$, the last term of (24) vanishes and the noise figure decreases as R_g increases. When the quantum efficiency is less than unity, the same term will contribute to the rise of

the noise figure for large source resistance. Differentiating (24) with respect to R_g gives the optimum source resistance for minimum noise figure.

$$R_g = N r_d \sqrt{\frac{2\eta}{(1-\eta)\mu}\left(\frac{r_s}{r_d}+\frac{\mu}{2}\right)} \qquad (25)$$

The corresponding minimum noise figure is then given by

$$F(\min) = 1 + 2\sqrt{\left(\frac{1-\eta}{\eta}\right)\left(\frac{r_s}{r_d}+\frac{\mu}{2}\right)\frac{\mu}{2}} \qquad (26)$$

which is independent of the number of light emitters used. In practice, finite bias resistances will increase *F(min)* slightly.

For the purposes of verification of the operation of the photon coupled amplifier of Figure 1, an photon coupled amplifier based on a Hamamatus type L2656 AlGaAs/GaAs Heterojunction LED was modelled in Pspice using known techniques. The parameters used for the LED were : r_d = 34.4Ω (at 1 mA), r_s = 3.6 Ω μ = 1.323 and τ_c = 0.297 μs. With V_g = 1 μV, R_g = 160 Ω R_1 = R_2 = 100 kΩ, N = 1 and η = 0.95, the current gain of the amplifier is obtained as shown in Fig. 5. Curves (a), (b) and (c) are the current gains with the feedback resistance equal to 30, 15 and 7.5 kΩ respectively. It is clearly demonstrated that, as positive feedback is increased, the current gain goes up and the bandwidth decreases correspondingly. Fig. 6 shows the frequency spectra of the output signal and noise currents of the amplifier with the same parameters used to obtain curve (b) in Fig. 5. With constant input voltage, the 3-dB bandwidth of the output current spectrum is wider than that of the current gain response because the input current i_l increases at high frequencies due to the shunting effect of the LED capacitance. The output SNR at low frequencies can be obtained directly from the spectral plots which is 54.25 dB and the input SNR obtained from (21) is 55.77 dB, thus giving a noise figure of 1.52 dB which agrees with calculation by (22).

Fig. 7 shows the noise figure of the positive feedback amplifier with a single LED in the array (N=1). The results are calculated as a function of the source resistance using the general expression (22) with $R_1 = R_2 = 100$ kΩ. Curve (a) is for the ideal case of η=1. The noise figure decreases monotonically to 0 dB as the source resistance increases. This is due to high impedance suppression of the shot noise in the LED. Approximately the same noise figure is obtained when the feedback factor is varied between 0 and 1.

Curves (b) and (c) are the noise figures obtained for η=0.95 and 0.9, respectively. In both cases, increasing the source resistance no longer reduces the amplifier noise figure monotonically. As the source resistance increases, the short noise is suppressed as before but the partition noise which increases as η decreases, becomes dominant hence causing an increase in noise figure. As the source resistance becomes very small, the shot noise current through the LED gradually increases, again causing an increase in noise figure. A minimum noise figure occurs at some intermediate value of the source resistance. For example in curve (b), the minimum noise figure is 1.15 dB and the optimum value of R_g is 160Ω which agrees with calculation using (25). Fig. 7 also shows that the noise figure of the feedback amplifier improves as η increases. This is obviously due to the reduction of partition noise in the amplifier at high quantum transfer efficiency.

Referring to Fig. 8, the current modulator formed by V_g and R_g in Fig. 1 is replaced by an input light detecting system, ILD. The current generated by ILD when light falls on it is used to modulate the array of light emitters. This current is amplified in the same way as in the form of the invention shown in Fig. 1, with the TDA bias and OLD bias currents provided in the same way. Resistance R3 and voltage supply V_b provide DC bias current for the output light emitting array, OTDA.

The output current from OLD is used to modulate the current in the laser diode or light emitting array, OTDA. Capacitor C3 couples the signal from OLD to OTDA. Impedances Z_1 and Z_f together determine the feedback factor β. The circuit functions as a low noise light amplifier.

Another embodiment of the invention is shown in Fig 9. In Fig 9 the LED array labelled TDA shown in Fig. 1 consists of a single light emitting diode or laser diode and the detecting system consists of a single detector.

Providing the quantum transfer efficiency, otherwise called the open–loop current gain, between the light emitting element and the detector is greater than one half, the closed– loop current gain of this configuration can exceed unity. In this form of the invention a current gain exceeding unity can thus be obtained by applying positive current feedback from a single detector to a single emitter.

Referring to Fig. 9, voltage source υ_s, with resistance R_s, generates current i_s to drive the light emitter *LE* through coupling capacitor C_s. The DC bias current for the semiconductor light emitting junction is provided through resistance R_1 from the positive voltage power supply *V+*. Semiconductor light detector *LD* is optically coupled to light emitter *LE* to provide open–loop current transfer ratio ($\eta = i_o / i_d$) of at least one half. DC bias current for the semiconductor junction diode detector is provided through resistance R_2 from power supply *V–*. Positive current feedback is provided via capacitor C_f. The output signal may be measured in the form of a voltage drop across impedance Z_0.

The use of high impedances for R_2, R_l and Z_s is necessary to obtain large suppression of the diode shot noise current which may otherwise flow through the light emitting element and be amplified. Almost all the output current i_o then flows back via C_f through the light emitter *LE* and the closed loop current gain is then approximately equal to $\eta/(1-\eta)$.

Photon partition noise is minimised by arranging the open–loop current transfer ratio, otherwise called the quantum transfer efficiency, to be as close to unity as possible.

The circuit of Fig. 9 can also be used as the basis of a lightwave amplifier and receiver by inputting light directly to detector *LD*.

It will be apparent that the best performance of the photon coupled circuit according to this invention is achieved using a single mode laser diode, resonant cavity LED, or micro cavity

laser diode or LED with the highest possible quantum efficiency. Currently available LEDs have an external efficiency at room temperature in excess of 85%.

CLAIMS

1. A low noise photon coupled circuit comprising a high quantum efficiency semiconductor light emitter, means to provide a bias current to said light emitter, the light output of said light emitter being modulated by the current flowing therein; a semiconductor light detector optically coupled with high quantum efficiency with said light emitter; means to provide a bias current to said light detector, the current flowing in said light detector being modulated by the light received from said light emitter, the quantum transfer efficiency of said circuit being greater than 0.5, and means to apply a feedback portion of the current flowing in said light detector to reinforce or oppose the current flowing in the light emitter.

2. A photon coupled circuit as claimed in claim 1 wherein said feedback is positive to reinforce the current flowing in the light emitter and provide increased gain.

3. A photon coupled circuit as claimed in claim 1 wherein said feedback is negative to oppose the current flowing in the light emitter and provide an increased bandwidth.

4. A photon coupled circuit as claimed in any one of claims 1 to 3 wherein said light emitter comprises an array of semiconductor light emitters.

5. A photon coupled circuit as claimed in claim 4 wherein said array comprises a plurality of laser diodes or light emitting diodes connected in series, and modulated by a common current modulator.

6. A photon coupled circuit as claimed in claim 4 or claim 5 wherein the product of the number of elements in the array and the value of the quantum coupling efficiency between each element and the light detector is much greater than 1.

7. A photon coupled circuit as claimed in any one of claims 1 to 3, wherein said light emitter is a single semiconductor device and said light detector is a single semiconductor device.

8. A photon coupled circuit as claimed in claim 7, wherein said semiconductor device comprising the light emitter is a single light emitting diode or laser diode.

9. A photon coupled circuit as claimed in any one of claims 1 to 8 wherein the light detector comprises a photodiode.

10. A photon coupled circuit as claimed in any one of claims 1 to 9 wherein the high quantum efficiency coupling of said light emitter with said light detector is achieved by close physical positioning.

11. A photon coupled circuit as claimed in any one of claims 1 to 9, wherein the high quantum efficiency coupling of said light emitter with said light detector is achieved via an optical waveguide or high efficiency light pipe.

12. A photon coupled circuit as claimed in claim 10 or claim 11 wherein said circuit is in the form of an optoelectronic integrated circuit.

13. A photon coupled circuit as claimed in any one of claims 1 to 12 wherein the quantum transfer efficiency of said coupling is at least 75%.

14. A photon coupled circuit as claimed in any one of claims 1 to 13 further comprising a second semiconductor light detector, the output current of said second light detector modulating the current flowing in said light emitter.

15. A photon coupled circuit as claimed in any one of claims 1 to 13 wherein said light detector is adapted to receive an input light signal from an external source and the current flowing in the light detector is modulated by the input light signal.

16. A photon coupled circuit as claimed in claim 15 further comprising a light output device driven by the amplified current from said light detector.

17. A photon coupled circuit as claimed in claim 16 wherein said light output device comprises one or more laser diodes or light emitting diodes.

18. A photon coupled circuit substantially, as described with reference to Figures 1 to 7, Figure 8 or Figure 9 of the accompanying drawings.

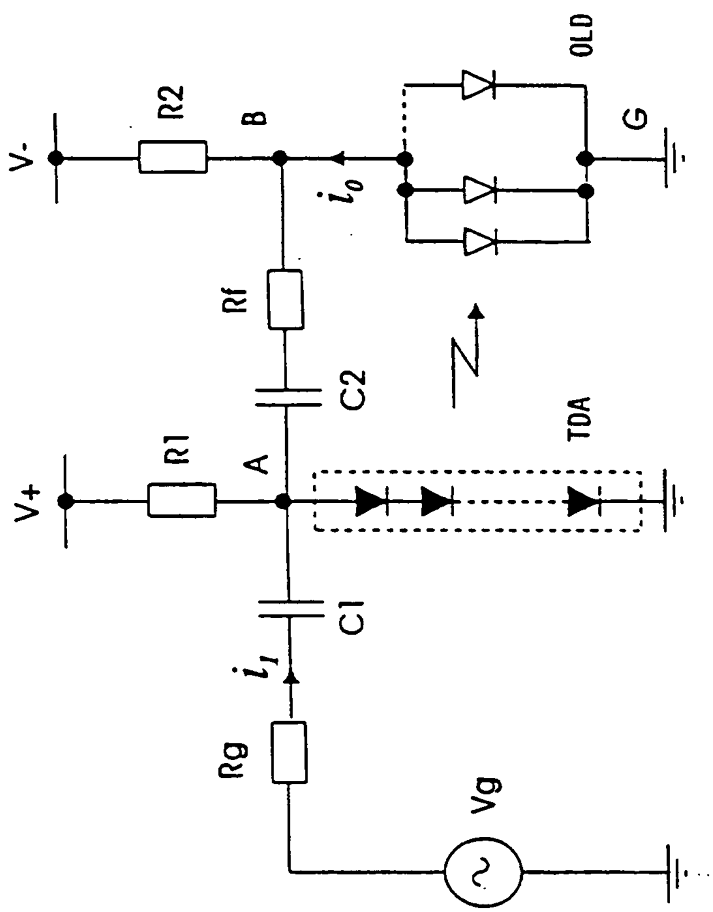

FIGURE 1

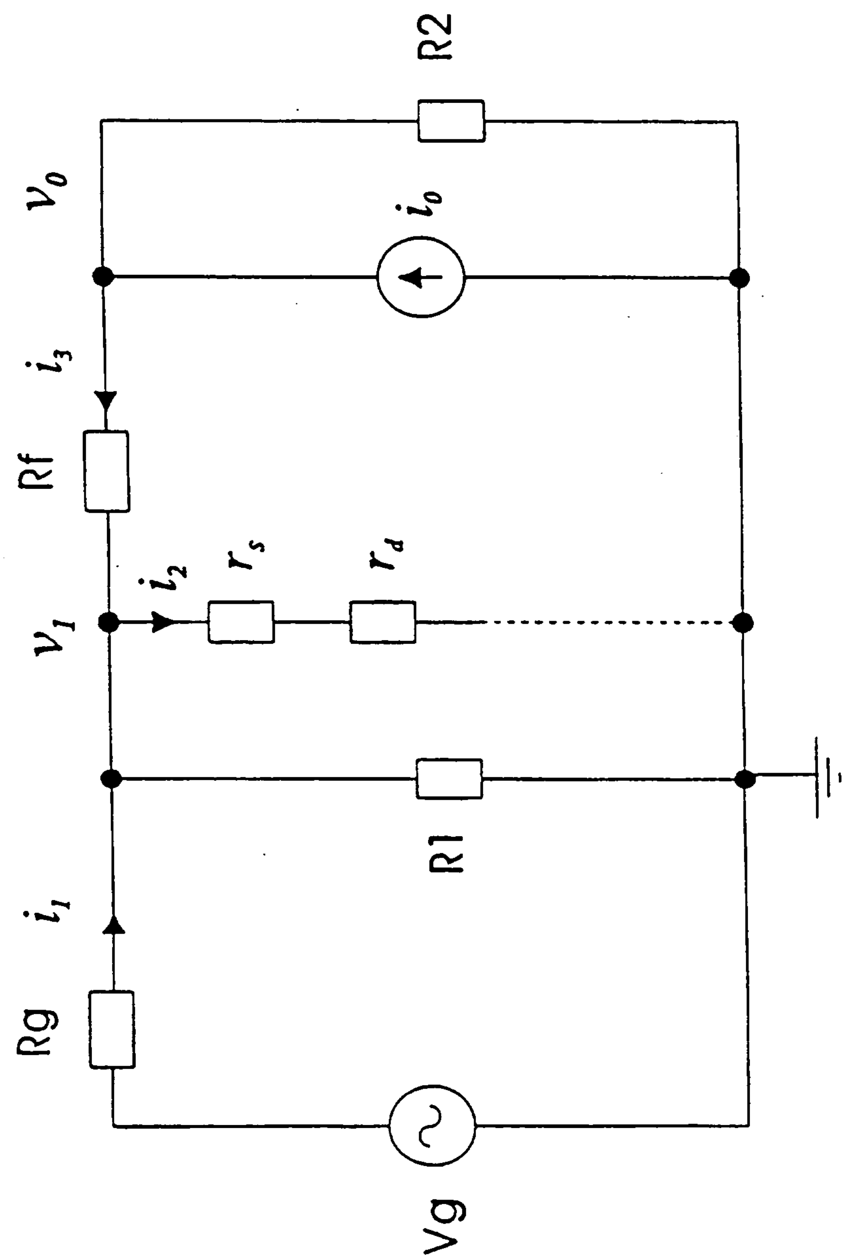

FIGURE 2

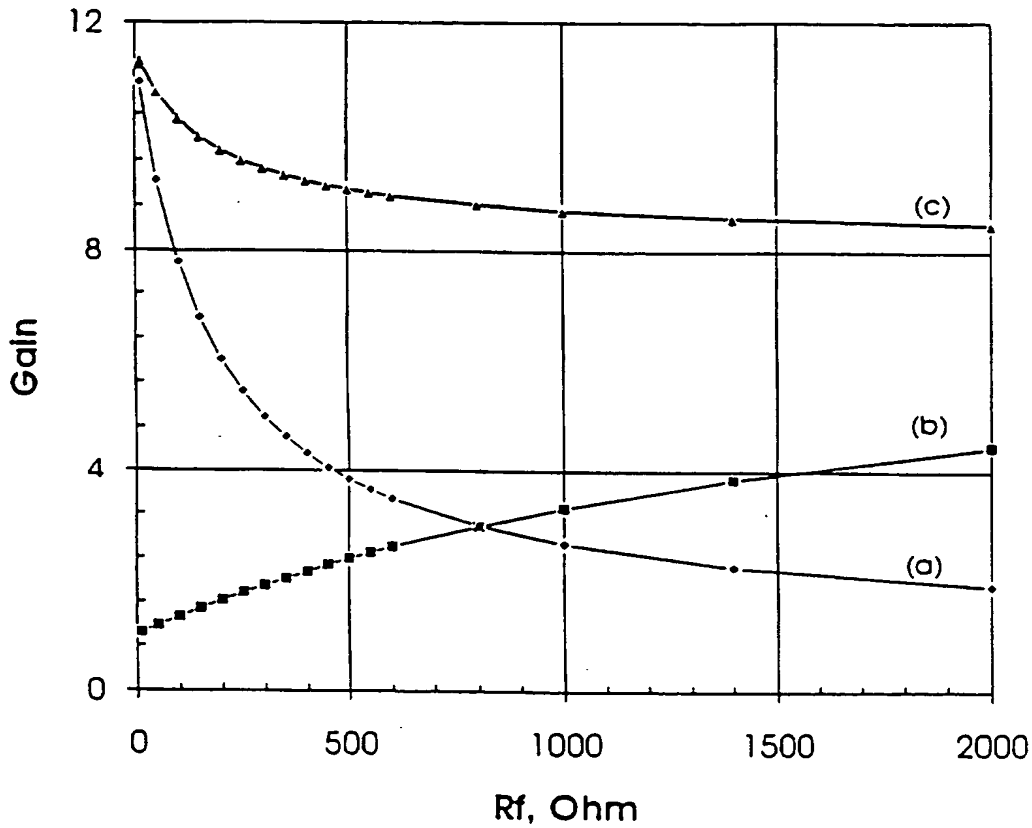

FIGURE 3

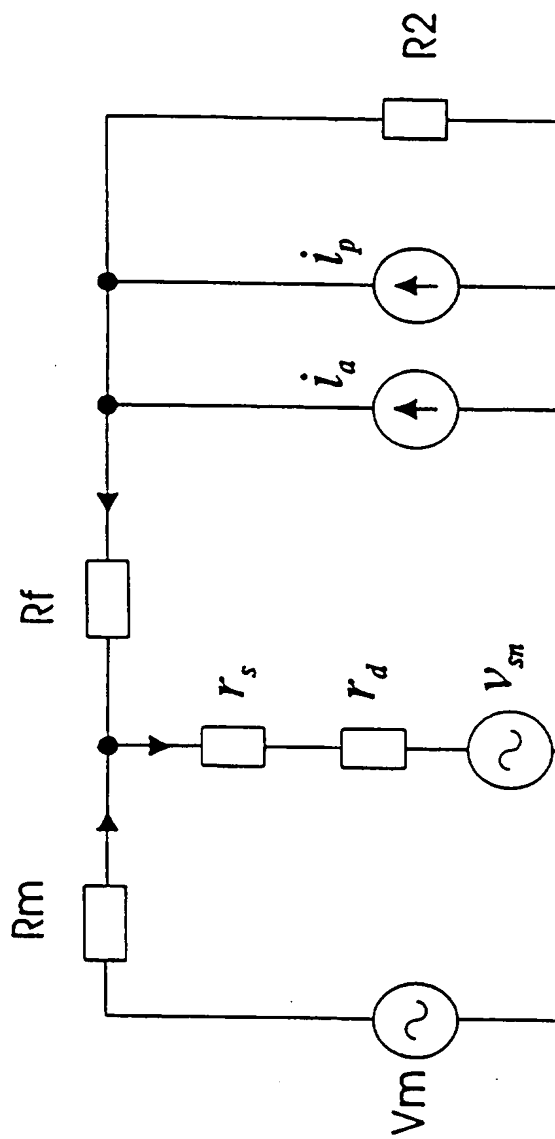

FIGURE 4

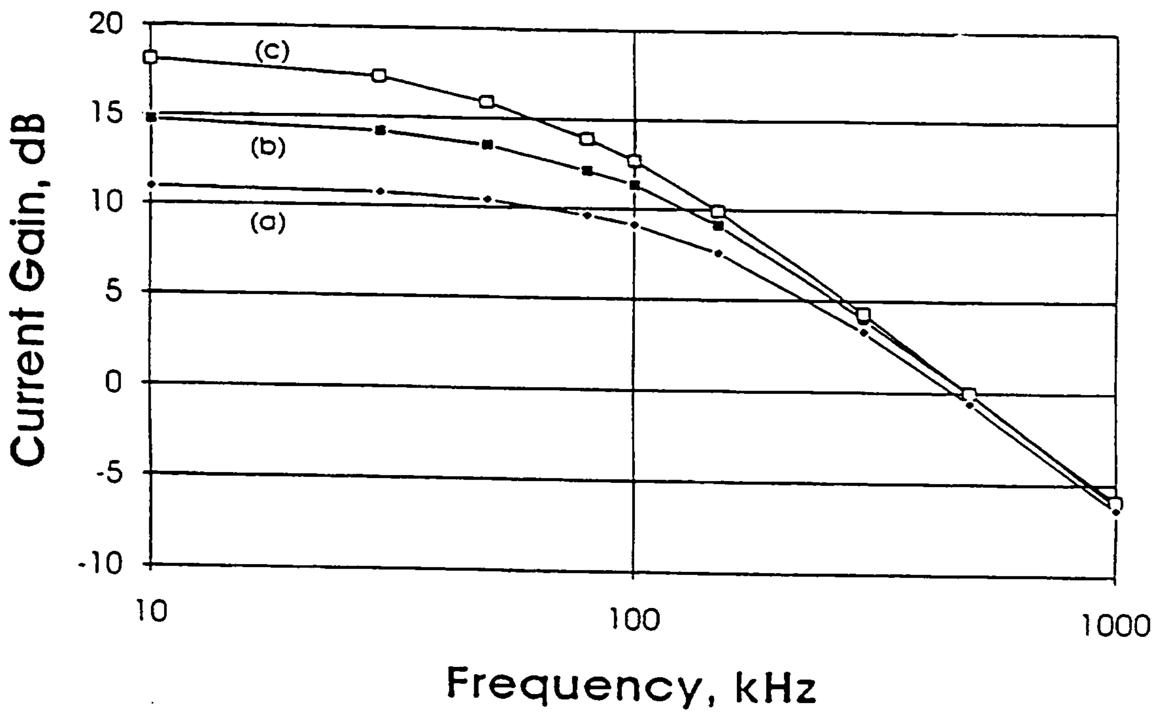

FIGURE 5

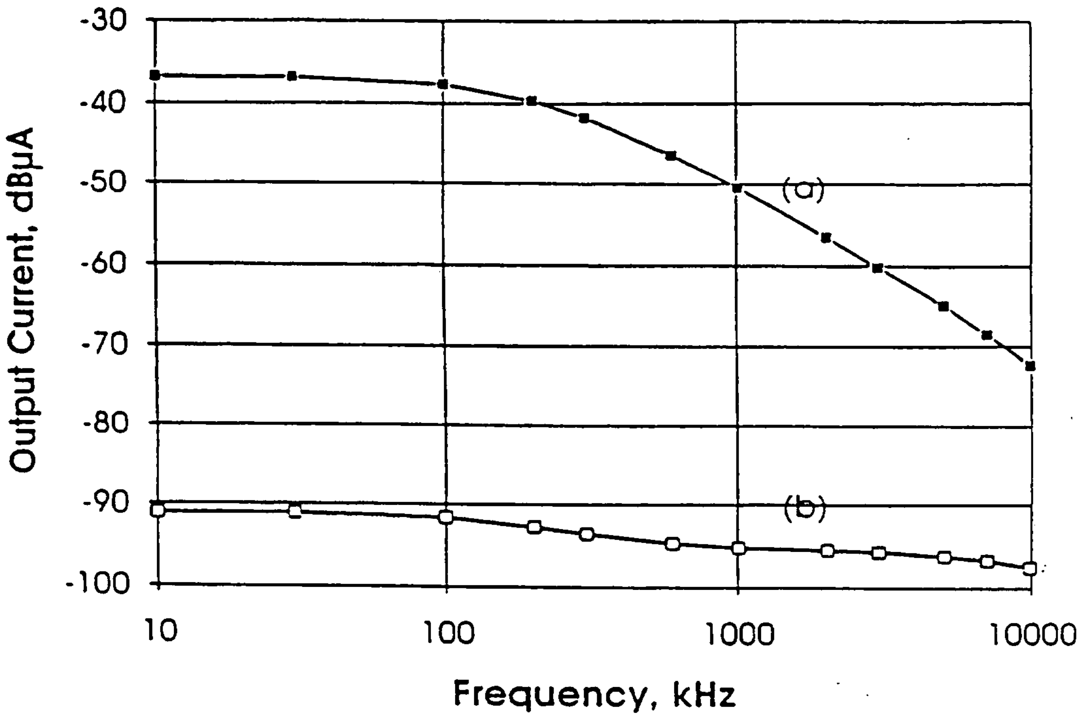
-30
-40
-50
-60
-70
-80
-90
-100
Output Current, dBµA
(a)
(b)
10
100
1000
10000
Frequency, kHz

FIGURE 6

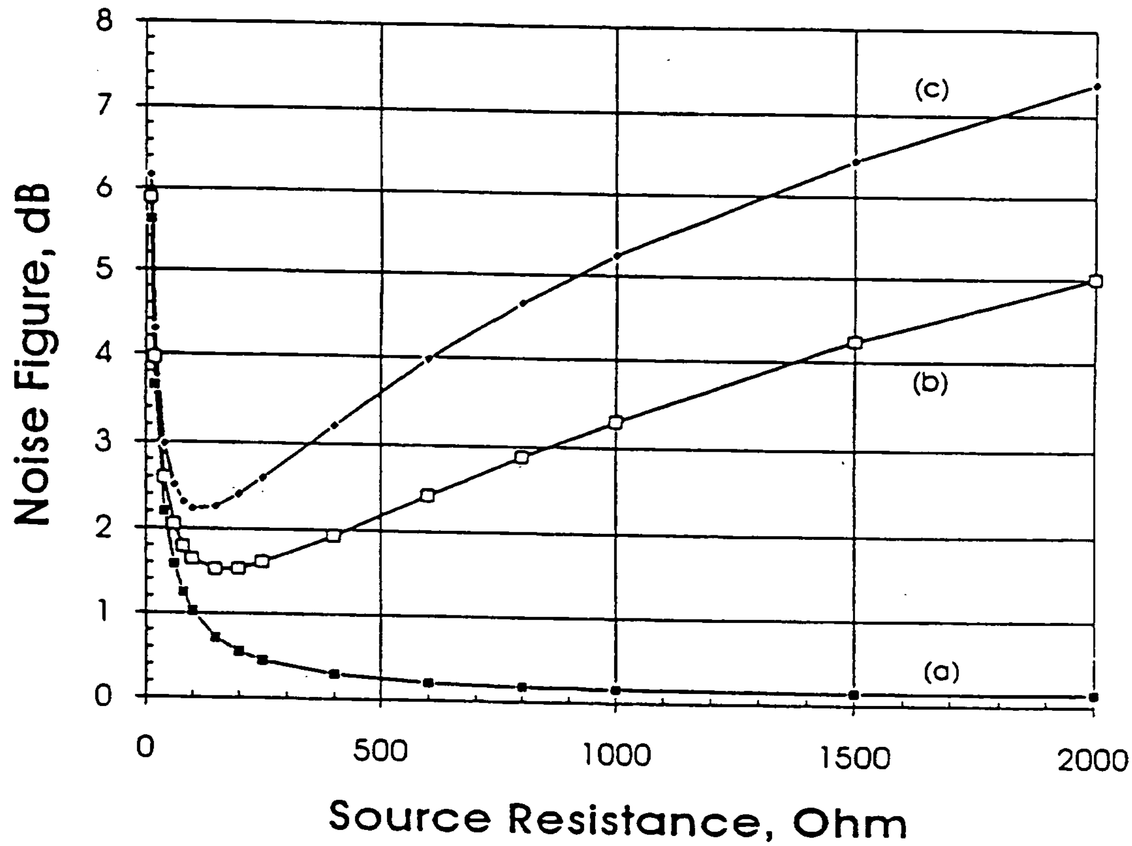
8
7
6
5
4
3
2
1
0
Noise Figure, dB
0
500
1000
1500
2000
Source Resistance, Ohm
(c)
(b)
(a)

FIGURE 7

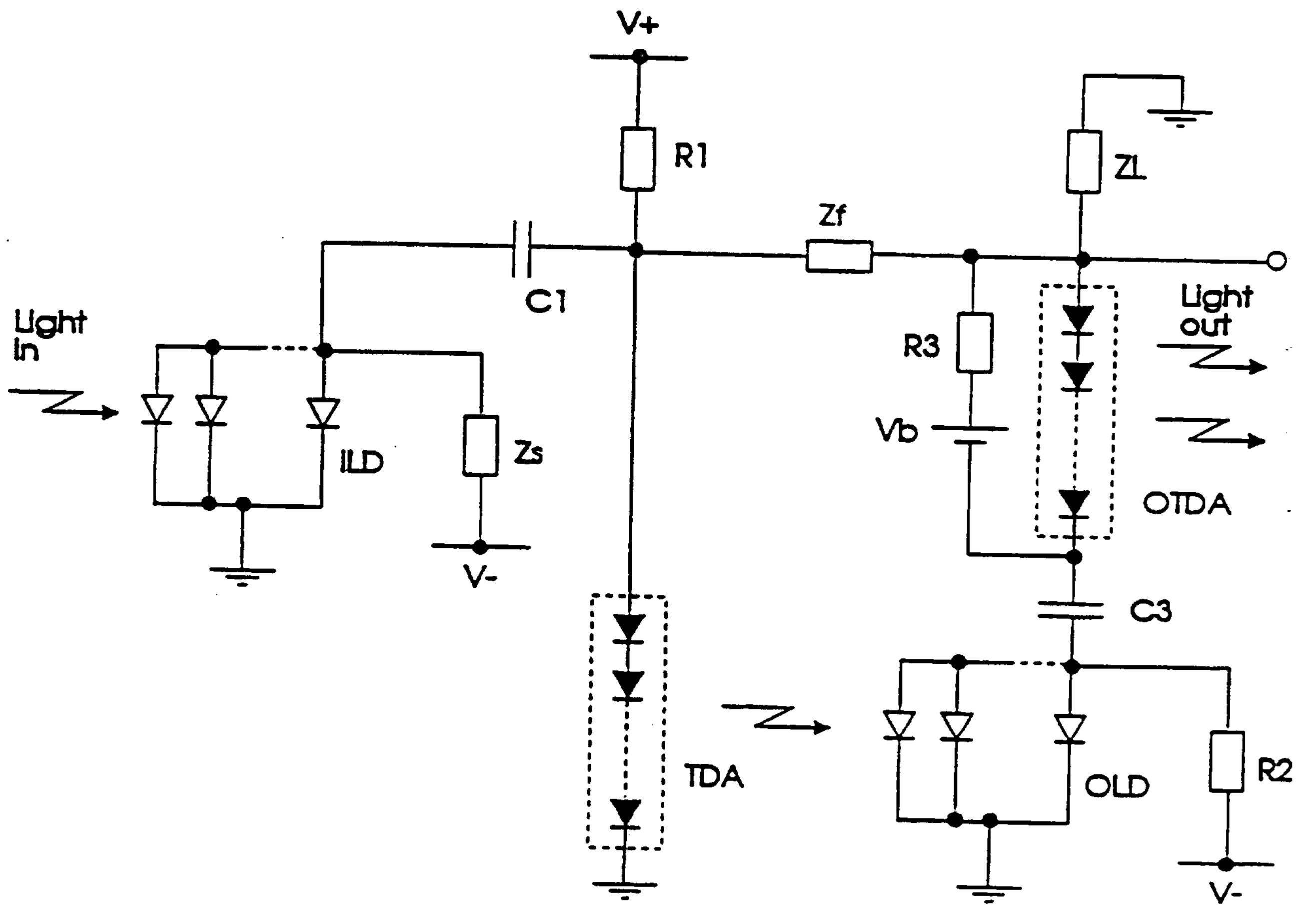

FIGURE 8

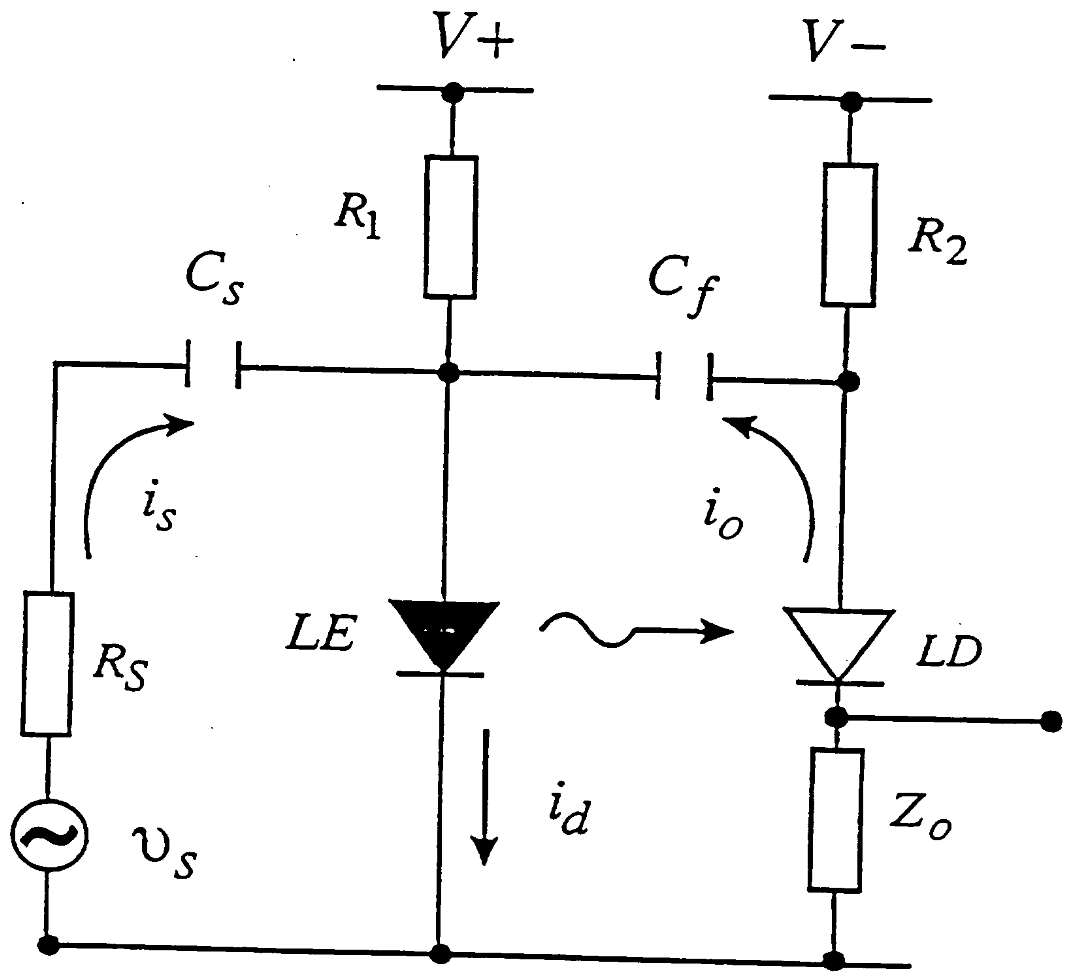

FIGURE 9

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 95/00599

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[6]: H01S 3/096 3/13 3/25 H03F 17/00 H03G 3/20 H04B 10/14 10/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : H03 H04 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 4450564 A (MEULEMAN et al) 22 May 1984	
X	entire document	1-3,7-10,15-17
Y	entire document	4-6,13
	US 5097473 A (TAGUCHI) 17 March 1992	
X	col 4 line 16 - col 5 line 31, col 11 lines 11-57, Figures	1-3,7-11,15-17
Y	col 4 line 16 - col 5 line 31, col 11 lines 11-57, Figures	4-6,13
	US 5123024 A (DOWD et al) 16 June 1992	
X	entire document	1-3,7-9,11,15-17
Y	entire document	4-6,13

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

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"&" document member of the same patent family

Date f the actual completion of the international search 30 N vember 1995	Date of mailing of the international search report 10 JAN 1996
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile N .: (06) 285 3929	Authorized fficer GREG POWELL T lephone No.: (06) 283 2308

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, f the relevant passages	Relevant to claim No.
	US 5268916 A (SLAWSON et al) 7 December 1993	
X	col 3 line 36 - col 4 line 57, Fig 2	1-3,7-10,15-17
Y	col 3 line 36 - col 4 line 57, Fig 2	4-6,13
	US 5278515 A (MATHEWS) 11 January 1994	
X	col 1 line 14 - col 3 line 57, Figs 1,2	1-3,7-10,15-17
Y	col 1 line 14 - col 3 line 57, Figs 1,2	4-6,13
	FR 2582887 A (LABORATOIRE CENTRAL DE TELECOMMUNICATIONS S.A. et al) 5 December 1986	
X	page 2 line 29 - page 4 line 29, Fig 2	1-3,7-10,15-17
Y	page 2 line 29 - page 4 line 29, Fig 2	4-6,13
	Patent Abstracts of Japan E-666, page 6, JP 63-122291 A (HITACHI LTD) 26 May 1988	
X	abstract	1-3,7-10,15-17
Y	abstract	4-6,13
	Patent Abstracts of Japan E-840, page 94, JP 1-194372 A (SUMITOMO ELECT IND LTD) 4 August 1989	
X	abstract	1-3,7-10,15-17
Y	abstract	4-6,13
	Patent Abstracts of Japan E-1266, page 61, JP 4-157781 A (RICOH CO LTD) 29 May 1992	
X	abstract	1-3,7-10,15-7
Y	abstract	4-6,13
	AU 21033/92 A (EDWARDS) 18 February 1993	
Y	entire document	4-6,13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No.
PCT/AU 95/00599

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Patent Document Cited in Search Report		Patent Family Member					
US	4450564	AU	75215/81	CA	1186379	DE	3163309
		EP	48057	JP	57081739	NL	8005153
US	5097473	EP	434466	KR	9411268	JP	4208581
US	5123024	DE	4225621	GB	2258561	JP	5198877
US	5268916	CA	2098343	EP	574816	JP	6085363
US	5278515						
FR	2582887						
AU	21033/92						

END OF ANNEX

PCT

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International Bureau

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(51) International Patent Classification 6 :
H01S 3/096, 3/13, 3/25, H03F 17/00, H03G 3/20, H04B 10/14, 10/16

A1

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(22) International Filing Date: 14 September 1995 (14.09.95)

(30) Priority Data:

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PM 9986	12 December 1994 (12.12.94)	AU

(71)(72) Applicants and Inventors: EDWARDS, Paul, Julian [AU/AU]; 3 Redgrove Place, Chapman, ACT 2611 (AU). CHEUNG, Wood, Nang [AU/AU]; 19 Sherlock Street, Kaleen, ACT 2617 (AU).

(74) Agents: LESLIE, Keith et al.; Davies Collison Cave, 1 Little Collins Street, Melbourne, VIC 3000 (AU).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).

Published

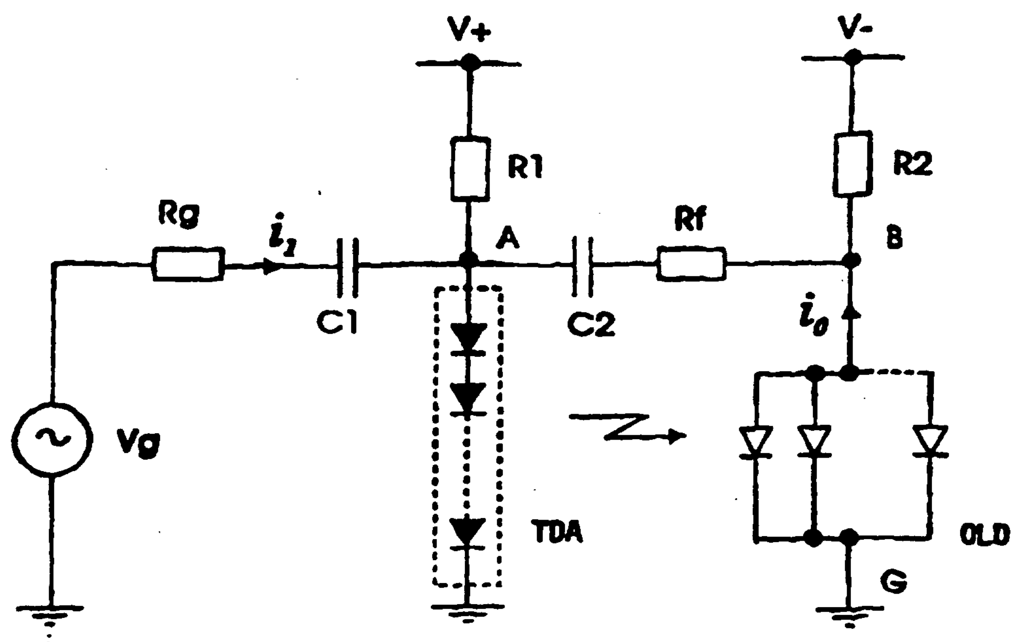
With international search report.
With amended claims.

Date of publication of the amended claims: 18 April 1996 (18.04.96)

(54) Title: A LOW NOISE PHOTON COUPLED CIRCUIT

(57) Abstract

A photon coupled circuit comprises a high quantum efficiency semiconductor light emitter (TDA) coupled with high quantum efficiency with a semiconductor light detector (OLD). Bias current is provided to both the light detector (OLD) and light emitter (TDA). The light output of the light emitter (TDA) is modulated by the current flowing therein and the current flowing (i_o) in the detector (OLD) is modulated by the light received from the light emitter (TDA). The quantum transfer efficiency or current gain in greater that 0.5 and a portion of the current flowing in the light detector (OLD) is applied as feedback to reinforce or oppose the curent flowing in the light emitter (TDA).



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GA	Gabon				

AMENDED CLAIMS

[received by the International Bureau on 7 March 1996 (07.03.96); original claims 1-18 replaced by amended claims 1-17 (3 pages)]

1. A low noise photon coupled circuit comprising a high quantum efficiency semiconductor light emitter, means to provide a bias current to said light emitter, the light output of said light emitter being modulated by the current flowing therein; a semiconductor light detector optically coupled with high quantum efficiency with said light emitter; means to provide a bias current to said light detector, the current flowing in said light detector being modulated by the light received from said light emitter, the quantum transfer efficiency of said circuit being greater than 0.5, and means to apply a feedback portion of the current flowing in said light detector to reinforce the current flowing in the light emitter.

2. A photon coupled circuit as claimed in claim 1 wherein said feedback is positive to reinforce the current flowing in the light emitter and provide increased gain.

3. A photon coupled circuit as claimed in claims 1 and 2 wherein said light emitter comprises an array of semiconductor light emitters.

4. A photon coupled circuit as claimed in claim 3 wherein said array comprises a plurality of laser diodes or light emitting diodes connected in series, and modulated by a common current modulator.

5. A photon coupled circuit as claimed in claim 3 or claim 4 wherein the product of the number of elements in the array and the value of the quantum coupling efficiency between each element and the light detector is much greater than 1.

6. A photon coupled circuit as claimed in claims 1 and 2 wherein said light emitter is a single semiconductor device and said light detector is a single semiconductor device.

7. A photon coupled circuit as claimed in claim 6, wherein said semiconductor device comprising the light emitter is a single light emitting diode or laser diode.

8. A photon coupled circuit as claimed in any one of claims 1 to 7 wherein the light detector comprises a photodiode.

9. A photon coupled circuit as claimed in any one of claims 1 to 8 wherein the high quantum efficiency coupling of said light emitter with said light detector is achieved by close physical positioning.

10. A photon coupled circuit as claimed in any one of claims 1 to 8, wherein the high quantum efficiency coupling of said light emitter with said light detector is achieved via an optical waveguide or high efficiency light pipe.

11. A photon coupled circuit as claimed in claim 9 or claim 10 wherein said circuit is in the form of an optoelectronic integrated circuit.

12. A photon coupled circuit as claimed in any one of claims 1 to 11 wherein the quantum transfer efficiency of said coupling is at least 75%.

13. A photon coupled circuit as claimed in any one of claims 1 to 12 further comprising a second semiconductor light detector, the output current of said second light detector modulating the current flowing in said light emitter.

14. A photon coupled circuit as claimed in any one of claims 1 to 12 wherein said light detector is adapted to receive an input light signal from an external source and the current flowing in the light detector is modulated by the input light signal.

15. A photon coupled circuit as claimed in claim 14 further comprising a light output device driven by the amplified current from said light detector.

16. A photon coupled circuit as claimed in claim 15 wherein said light output device comprises one or more laser diodes or light emitting diodes.

17. A photon coupled circuit substantially, as described with reference to Figures 1 to 7, Figure 8 or Figure 9 of the accompanying drawings.

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